Linear Collider Overview

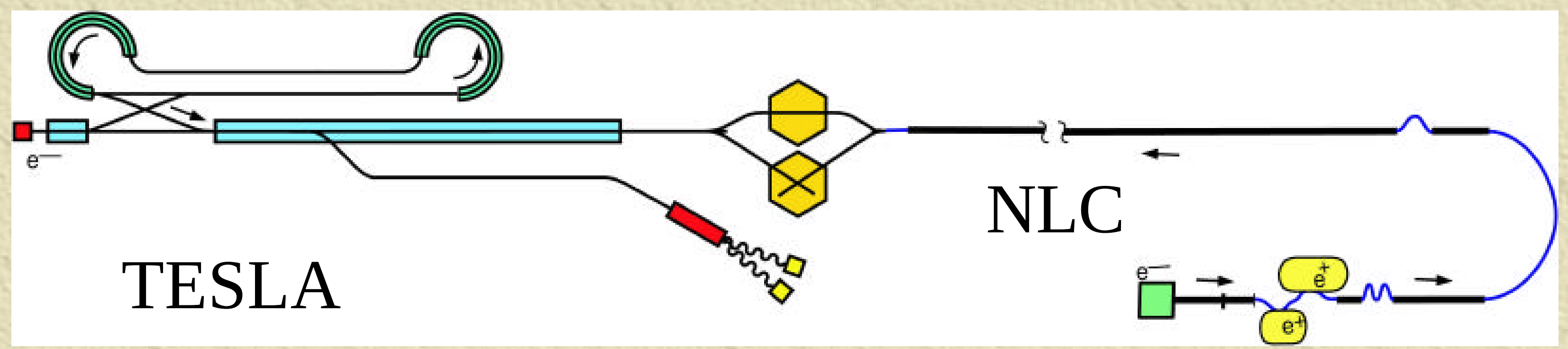
Status, challenges, R&D opportunities

Tom Himel
SLAC

Interaction Meeting on Linear Collider and Neutrino Physics
New Delhi Nov 10-12, 2003

Contents

- The two challenges:
  - Energy
  - Luminosity
- Some needed R&D



Selected Parameters

Parameter	**TESLA**	**NLC**	**Pro/con of TESLA**
RF Frequency (GHz)	1.3	11.4	+ Less wakefields and hence looser alignment tolerances
Repetition rate (Hz)	5	120	- Beam moves 20 sigma in 1/5 seconds.
# bunches/pulse	2820	192	- Needs very fast DR kicker
# bunches/sec	14,100	23,040	
DR circumference (m)	17000	300	- Caused by large number of bunches
Time between bunches (ns)	337	1.4	+ Allows easier intra-train feedback; + Less pile-up in the detector

http://www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm

Selected Parameters (cont)

Parameter	**TESLA**	**NLC**	**Pro/con of TESLA**
Energy (GeV)	500-800	500-1000	- Less max energy due to lower gradient
# particle/bunch	2	0.75	
Beam power (MW)	11.3	6.9	+ Allowed by higher RF to beam efficiency
Peak Luminosity (10^{33} cm^{-2} s^{-1})	34	20	+ Caused by higher disruption enhancement
Total length (km)	33	32	Nearly identical!
RF structure temperature (degrees K)	2	315	- Cryostat makes alignment harder
σ_x / σ_y	553 / 5	243 / 3	- σ_y larger due to bunch length

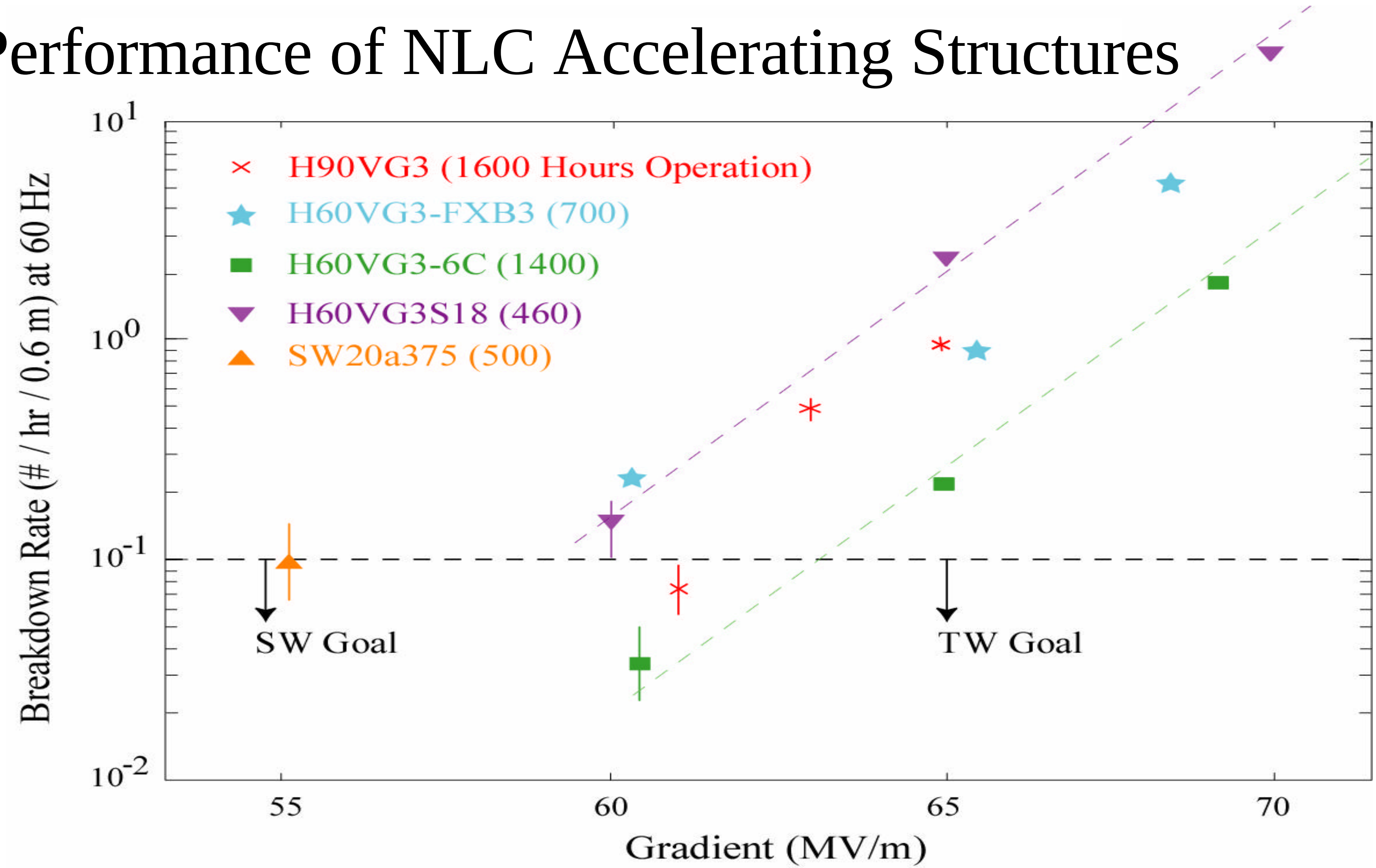
NLC Test Accelerator

Operated since 1996

Essentially NLC-500 rf system from 1996:

- Dual 50MW klystrons
- 40 MeV/m gradient
- SLED-II
- 1.8 m long structures

Performance of NLC Accelerating Structures



Expect to reach 65 MV/m. Fall-back of 60 MV/m operation has very little effect on total cost as gradient is near a flat cost minimum.

Plan to have 8 structures operating at full gradient in mid ’04.

Where does the x10^4 Luminosity increase come from?

$$L = \frac{f_{rep}}{4\pi} \frac{n_b N^2}{\sigma_x \sigma_y} H_D$$

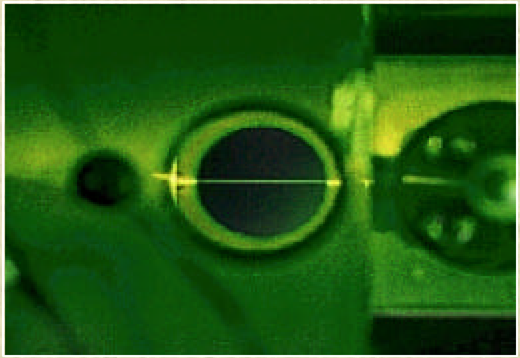
$$\frac{1}{\sigma_{IP}} = \sqrt{\frac{\gamma}{(\gamma\varepsilon)_{DR} \cdot Dilution_{DR \rightarrow IP} \cdot \beta_{IP}}}$$

SLC Luminosity x10^4

Where does it come from?

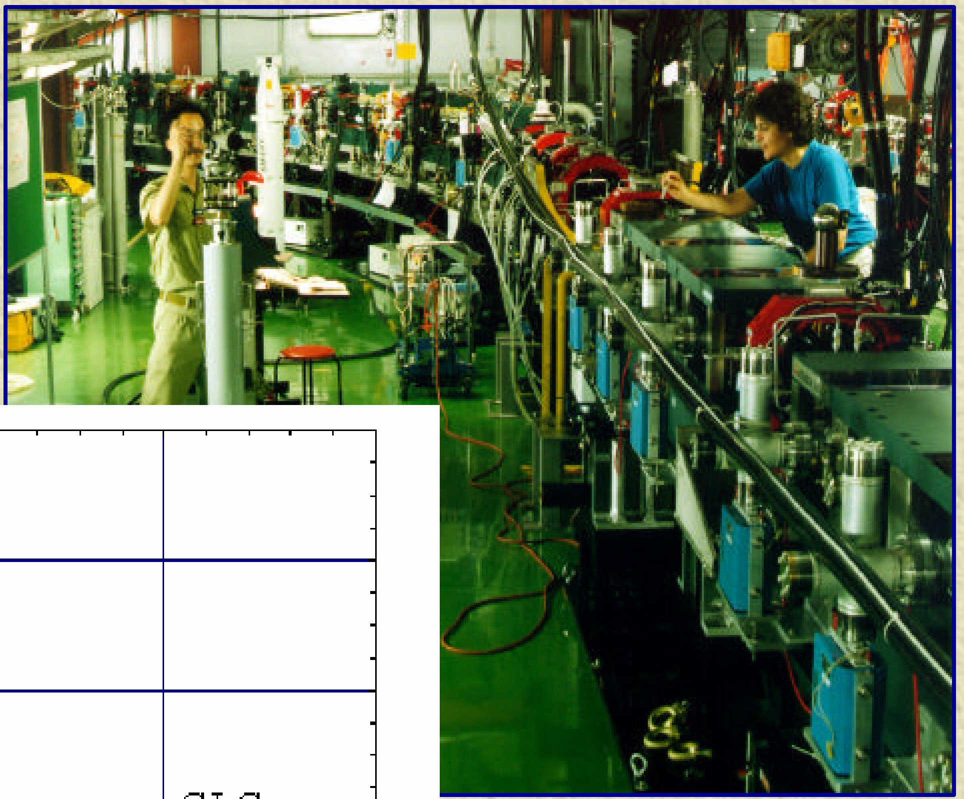
	NLC/ SLC	TESLA / SLC	Basis for Confidence
Energy, Beam Power, Q/bunch	34.6	152	“Free” and “Guaranteed”
Disruption (H_d)	0.72	1	Guinea Pig Studies
Damping Rings Sqrt(ε_x ε_y)	41	25	ATF
Emittance Preservation Sqrt (Dilution$_x$ Dilution$_y$)	2.24 (x41)	2.38 (x25)	ASSET Beam Based Alignment Studies
FF Demagnification Sqrt ($\beta_x\beta_y$)	3.27	1.20	FFTB
Total	7400	11300	

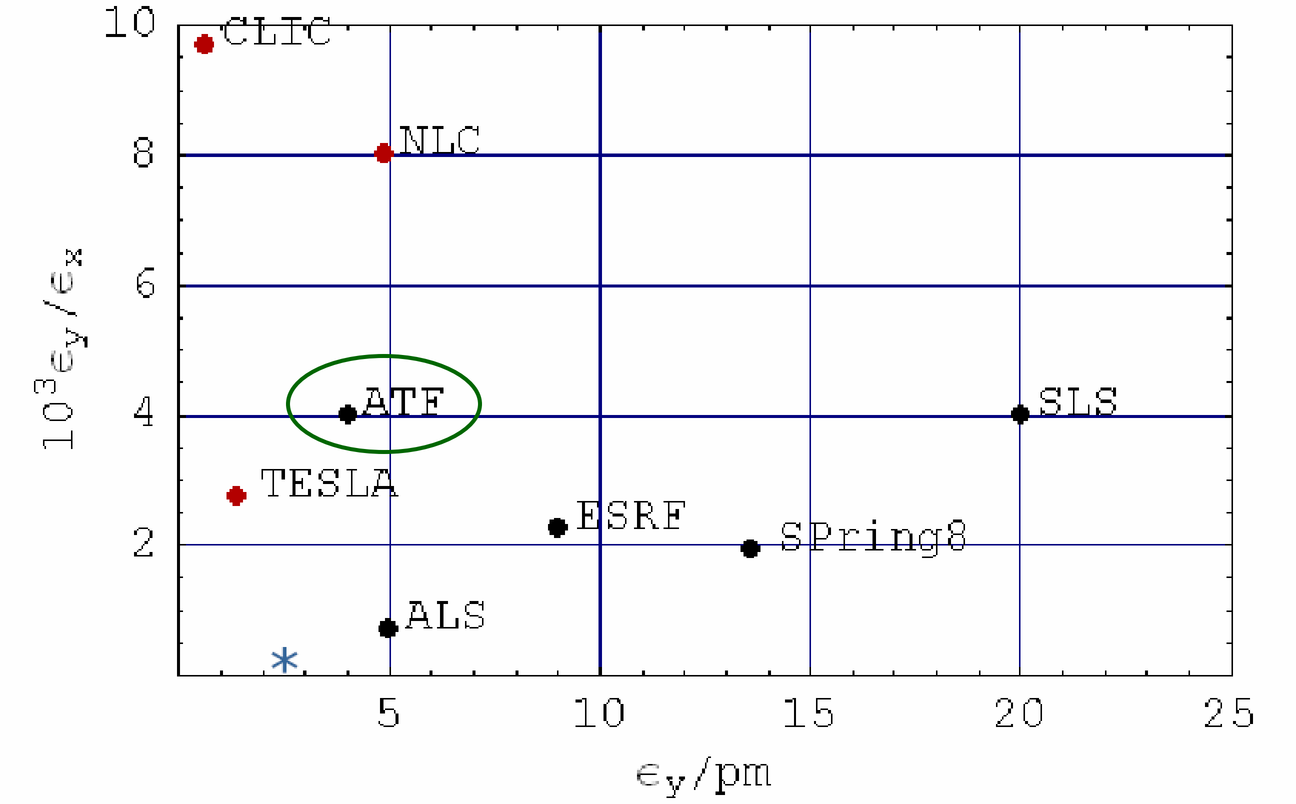
NLC prototype Damping Ring at KEK (ATF)



"Laser Wire"

SLAC and KEK physicists survey the ring.





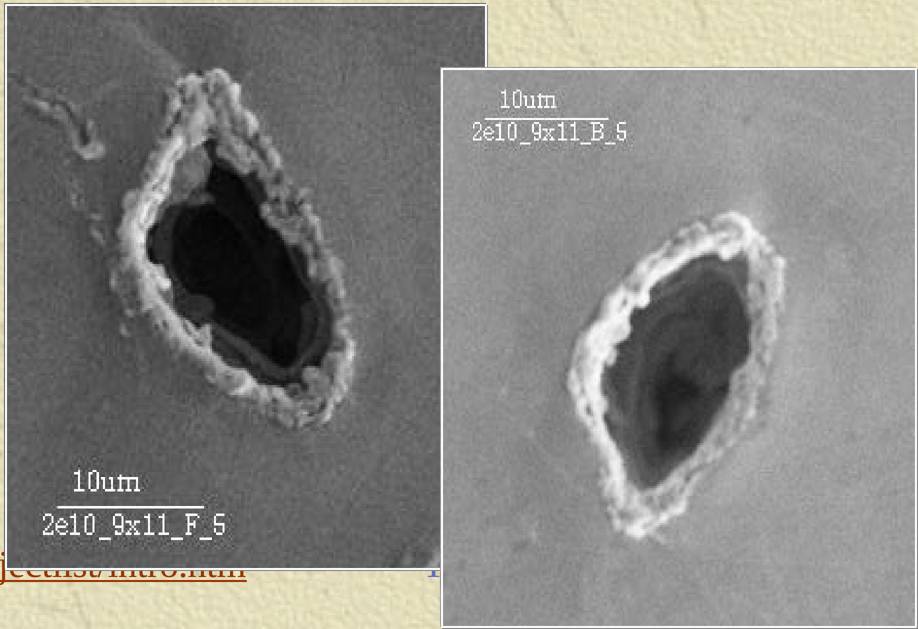
RF Cavity Alignment needed for emittance control

- NLC structures (cavities) must be aligned to beam within 5 μm rms for 10% Δε. Have presently demonstrated 11 microns in ASSET (was systematics limited by incoming beam jitter)
  - Every structure has two structure-BPMs with better than 2 μm accuracy
  - Short-range wakefields depend on average of structure offset
  - Average position of the 6 structures on an rf girder and move girder end-points with remotely controlled movers
- TESLA cavities must be aligned with 300 μm rms for 15% Δε
  - Achieved 250 μm RMS alignment within cryostat
  - Changes this much on temperature cycle
  - No movers or structure BPMs

Need for Hazard Avoidance Logic (HAL)

- Single bunches will likely damage any material at the end of the linac or in the beam delivery
  - Complicated turn-on process to prevent damage
  - Complicated MPS system with diagnostics on all components that can change from pulse-to-pulse
  - Some impact on operation not yet fully quantified
  - Problems are similar for TESLA and NLC!

Damage from 13 pC/μm^2 ($2x10^9$ e^-)



http://www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm

List of Extra R&D needs

- I'm walking on a tight rope
  - Want to convince you there are interesting, challenging R&D projects
  - Without convincing you the LC cannot be built.
- Very high priorities are being done: gradient, power source, FF design: not on project list.
- On list are items that if they can be done will decrease cost or improve reliability or reduce risk.
- Many items on list are challenging but pretty clearly doable. Doing them makes the CDR that much more definite and convincing, refines the cost estimates and gets work going that needs to be done.

http://www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm

THE LIST of projects

- In capitals. It dominated my life for a few weeks 1.5 years ago when I prepared it for a similar meeting aimed an American university researchers.
- http://www-conf.slac.stanford.edu/lcprojectlist/projectlist/intro.htm
- Input from SLAC, FNAL, Cornell. I just organized it.
- Wide range of skills, project sizes and priorities. Something suitable for everyone.
- It is now a little out-of-date as some projects now have a university group working on them.

Sample DB entry

ID: 16 **project_size:** Large **skill_type:** physicist

short project description: Very fast injection/extraction kickers for TESLA damping ring

Detailed project description: The 800 microsecond-long ‘macropulse’ of TESLA is equivalent to a length of 200 km, while the circumference of a damping ring is an order of magnitude less. The 0.3 microsecond spacing of TESLA bunches becomes 30 ns in the damping rings. So to inject or extract a single bunch, the kicker pulse must be limited to this time period. The current design concept is that each kicker consist of 20-40 individual modules, for a total of up to 160 modules in the two damping rings. Each unit would be about 0.3 m in length, with individual excitation. A number of kicker designs have been looked at and are considered feasible candidates. The challenge lies in the pulsers – namely the rise time, stability, ringing, and power requirementts. Pulser development currently needs both manpower and money, and a partner (or partners) to play a significant role is (are) welcome, as are new ideas. Voltage and current levels are moderately high at 5kV and 100 A respectively for present kicker module designs. Documentation is available upon request.

Needed by who: TESLA **present status:** In progress, help needed

ContactPerson1: Dan Wolff **WorkPhone1:** 6308404052
EmailAddress1: wolff@fnal.gov

Note that the contact person is someone who knows more about the project. He’s not the person who will arrange who works on what.

Background Calculation and Reduction in the IR.

- Size: Medium
- Skill: Simulations
- Needed for NLC and TESLA
- There are many types of backgrounds: Halo muons, low energy e+e- pairs, synchrotron radiation.
- Use existing simulation tools (and perhaps write new ones) to calculate the background levels and to design shielding and masks to minimize it.
- A fair amount of work has been done, but more is needed.

Damping Ring Electron Cloud Remediation

- Size: Large
- Skill: Materials Science
- Needed for NLC and TESLA
- The positron damping rings will suffer from an electron cloud instability unless the Secondary Emission Yield can be made less than 1.1 in some vacuum chambers. This has been done on small samples but not in 100's of meters of a real ring. TiN surface coating is usually used.
- LHC needs this too. BNL is doing some work on it.

Magnet and Power Supply Reliability

- Size: Large
- Skill: Engineer
- Needed for NLC and TESLA
- Recent reliability studies have highlighted water cooled magnets and their power supplies and power supply controllers as needing to be an order of magnitude more reliable than those used in present accelerators.
- Examine present failure modes, design and test enough devices to demonstrate the needed availability improvement.

Design and prototype Low Level RF electronics

- Size: Large
- Skill: Electronics
- Needed for NLC and TESLA, but different
- Both NLC and TESLA have thousands of channels of LLRF electronics. Both have working prototype systems. A good modularized, reliable, **cheap** design is needed.
- This is likely to involve custom chip design and manufacture.

Monitor Luminosity as Function of CM Energy

- Size: Medium
- Skill: Conceptual design
- Needed for NLC and TESLA
- Beamstrahlung causes an energy spread in the CM energy with a long low energy tail. A detector is needed to measure this luminosity distribution. Perhaps the beamstrahlung photon spectrum could be used?

DR beam dynamics simulation and design optimization

- Size: Medium
- Skill: Accelerator physics
- Needed for NLC and TESLA
- Improve the DR designs:
  - Maybe the NLC DR aperture can be improved to the point where the e+ pre-damping ring isn't needed.
  - Maybe the TESLA DR aperture can be improved so it is greater than the size of the incoming positron beam
- Tuning algorithms and simulations are needed.

Accelerator Control and Machine Protection System (MPS)

- Size: large
- Skill: Electronics and Software
- Needed for NLC and TESLA
- The sort of control systems, hardware, software, feedbacks, and data acquisition that we have now are probably not what will ultimately be wanted or needed for LC accelerator control. Work should begin now on specification of requirements and how best to plan to deal with them. The MPS is a particularly important system as it must protect the machine but still allow it to run efficiently. The logic of this system and its interfaces are at the heart of just how the LC will operate.

Flow switch

- Priority: Medium
- Size: Small
- Skill: Electronics and Mechanical
- Needed for NLC and TESLA
- High reliability, cheap, rad-hard flow switch. Should not trip when a bubble goes by, should not be the smallest aperture in the system so that it gets plugged up. Should both have a trip point and a flow readout so marginal flow can be detected before it causes a trip.

Fast communications to check pulsed devices (part of HAL)

- Size: Small
- Skill: Electronics and Mechanical
- Needed for NLC and TESLA
- Part of HAL that must check that all pulsed devices (modulators and kickers) are ready to fire just before the particles are extracted from the damping rings. If too many things aren't ready (a few bad modulators may be OK) then DR extraction is aborted. This must be very fast (speed of light should account for most of the delay), so simple logic and wires or fibers must be used. Design such a system to be highly reliable and have necessary diagnostics and readout of what caused the fault. Only a conceptual design is needed at this point.

Robot to replace electronic modules in tunnel

- Size: Large
- Skill: all
- Useful for NLC and TESLA
- Very serious consideration is being given to putting much of the electronics in the accelerator tunnel. To make this more palatable as far as reliability is concerned, it would help to have robots in the accelerator tunnel that could change modules. Perhaps they would travel on rails attached to the wall. For this to work will require both a good electronics enclosure and cabling design and a good robot design.

Summary

- TESLA and NLC designs are more similar than they are different.
- No showstoppers!
  - Many outstanding problems in both designs
  - 2^{nd} generation prototype hardware still needs demonstration
  - Most failures can be worked around
- Lots of challenging, fun, useful R&D projects to do.
- Let's get to work!!